Cruft Laboratory
Harvard University
Cambridge, Massachusetts

PROGRESS REPORT NO. 32

COVERING PERIOD
APRIL 1, 1954 – JULY 1, 1954

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July 1, 1954

Cruft Laboratory

Harvard University

Cambridge, Massachusetts

Progress Report No. 32

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Task Order 1 NR-071-012	Submitted by The Steering Committee
Task Order 28 NR-071-011	Submitted by H. R. Mimno
Air Force Contract AF19(604)-786	Submitted by R. W. P. King
Air Force Contract AF19(604)-1084	Submitted by C. L. Hogan

July 1, 1954

Explanatory Note

Several changes have been made in the organization of this Progress Report. Section I now includes Electromagnetic Radiation, Microwave Circuits and Random Processes. The section on Electromagnetic Radiation includes a report on work carried out under Professor R. W. P. King's direction on Air Force Contract AF19(604)-786; and the section on Microwave Circuits includes work under Professor C. L. Hogan's direction, on Air Force Contract AF19(604)-1084, as well as some of the projects previously reported under Electron Physics (previously III-A). The section on Random Processes includes prcjects previously reported under sections IV-A and IV-B.

In order to list together all the research supported by Project 1, the former sections II and III have been interchanged: Section II is now Electron and Solid State Physics and section III is now Wave Propagation. Under section II work is reported on properties of semiconductors under high pressure, which is largely supported by and partially staffed by Lincoln Laboratory but is closely coordinated with the rest of the Project 1 program.

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I

ELECTROMAGNETIC RADIATION, MICROWAVE CIRCUITS AND RANDOM PROCESSES*

Academic Staff: Prof. R. W. P. King
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I-A Antennas

I-A-1 Experimental Study of Collinear and Frame Slot Antennas at 10 cm. T. Kaliszewski.

Objective To study the transverse electric field distributions on complementary slot antennas such as the collinear, array, square and circular loops at 10 cm wavelength.

Practical Significance The application of Babinet's principle permits the determination of the distributions of current in practically important wire antennas.

Status Design and construction of an electric probe, guiding bridge and the slot array have been completed. The apparatus has been assembled and a complete set of measurements made on the collinear array. A technical report on this phase of the study is being prepared.

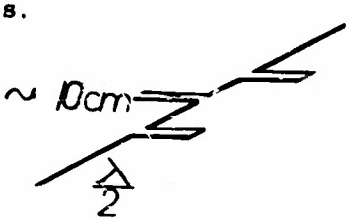

Fig. I-1 Collinear Slot Array

I-A-2 Diffraction by Dielectric Materials and the Radome Problem, T. T. Wu

Objective To investigate the general problem of diffraction of arbitrary waves by dielectric materials, especially in the form of closed envelopes.

Practical Significance An understanding of the nature of this kind of diffraction is prerequisite to its practical utilization, as in radomes.

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*Project 1 unless otherwise indicated.

Status An integral equation has been set up under quite general conditions. Attempts are being made to apply to this equation the powerful theorems developed in recent years for integral equations of the Fredholm type.

I-A-3 Propagation of Electromagnetic Waves into Conducting Dielectrics, A. Jayne.

Objective To study the propagation of electromagnetic waves into conducting dielectrics and to study the circuit and field properties of antennas for transmission into conducting dielectrics.

Practical Significance Electromagnetic prospecting, underground and underwater radiating systems and the transmission of radio signals into the upper atmosphere are all practical problems which require a knowledge of the propagation of electromagnetic waves into conducting dielectric media.

Status The search for a liquid suitable for use as the imperfectly conducting dielectric medium in the experimental measurements is continuing. For the initial measurements it is hoped to obtain a liquid with a dielectric constant approaching 20 and with loss tangent less than 0.1 at 10 cm wavelength and at room temperature.

In view of these requirements of relatively high dielectric constant and relatively low loss, it seemed that a polar liquid with large dipole moment and small relaxation time mixed with a non-polar or slightly polar liquid offered possibilities of being suitable. A large number of measurements have been made on various liquids and mixtures which seem to bear out this viewpoint. For instance, a solution of nitromethane and trichloroethylene (50 per cent CH_3NO_2, 50 per cent C_2HCl_3) was measured to have a dielectric constant of 17 and loss tangent of 0.13.

I-A-4 Antennas in and over Imperfect Dielectrics, S. Stein.

Objective To study the properties of antennas when immersed in or placed near conducting dielectrics.

Practical Significance Propagation over the earth, into the earth, and from one underground location to another, as well as the exploration of the earth by electromagnetic methods, requires a knowledge of the circuit and field properties of antennas near and in the earth.

Status The computations mentioned in Progress Report No. 28 have been resumed. No graphical results are yet available.

I-A-5 Control of Surface Currents, C. E. Faflick

Objective To study the properties of a lumped impedance section in linear antenna.

Practical Significance: A lumped impedance, such as a coaxial sleeve, placed along an antenna may be useful in controlling the surface currents to maintain a desired input impedance and field pattern. A knowledge of the control of surface currents is also useful in suppressing undesired currents on feed cables and in reducing scattering cross sections.

Status: The experimental aspect of this investigation has been completed and a technical report is under preparation.

I-A-6 Coupled Receiving Antennas, C. Moritz

Objective: A study of the behavior of the two-element array.

Practical Significance: Applications of the study of coupled receiving antennas are to direction-finding, directional receiving arrays, and by application of the reciprocal theorem, to directional transmitting arrays.

Status: Computations from the measurement data which have been obtained and reported in Progress Report No. 28 are continuing.

I-A-8 UHF Bridge Impedance Measurements, E. W. Matthews, Jr.

Objective: To investigate the use of bridges as impedance-measuring devices in the uhf range.

Practical Significance: A compact impedance bridge capable of rapid and accurate measurements in the uhf range would be a valuable supplement to conventional transmission-line methods.

Status: The experimental phase of this investigation has been completed and Technical Reports 183 and 184 have been issued.

I-A-10 Antenna Measurements on the Image-Plane Line, P. Kennedy

Objective: The research in this project is directed toward the general study of various types of antennas driven by an image-plane line.

Practical Significance: In order to provide complete data on the behavior of various types of antennas not applicable to coaxial line techniques and to verify theoretical studies, experimental measurements are required.

Status: A complete set of circular loops has been constructed to cover the range of measurements made previously with

square loops. Impedance measurements are in process but no evaluating of the data has yet been made.

I-A-13 The Square-Loop Antenna, R. W. P. King.

Objective — The determination of the distribution of current and the impedance of a square loop antenna as a function of its dimension and wire size. The loop may be driven at one or more corners or at the center of one or more sides; it may be loaded at one or more corners or at the centers of one or more sides.

Practical Significance — No solution of the circuit properties of square-loops of dimension comparable with the wavelength is available. Such loops have applications in direction-finders, beacons, etc.

Status — A theoretical study of the square-loop driven at each corner by arbitrary voltages is in progress. A superposition of the solutions of four independent integral equations corresponding to four phase sequences will yield the general solution for the current. Two of these equations have been derived and a formal solution obtained. Work is proceeding on the other two equations.

I-A-14 The Circular Loop Antenna, J. E. Storer.

Objective — To determine the current distribution and impedance of circular loop antennas.

Practical Significance — When the loop dimensions are comparable to the wavelength, numerical solutions of the loop impedance and current distribution have not been available.

Status — Calculations of the input impedances of symmetrically driven loops are approaching completion.

I-A-15 Discontinuities in Transmission Lines, R. W. P. King

Objective — To develop simplified methods for treating discontinuities and terminal-zone effects in open-wire, coaxial, and shielded-pair lines.

Practical Significance — The geometry of the junction between a transmission line and its load and discontinuities in a line may modify the behavior of the line as a tool in measurement or as a transmission circuit. By supplementing conventional line theory with a simple treatment of discontinuities the results of theoretical calculation become quantitatively useful in practice.

Status — This investigation has been completed and a technical report

(No. 200) is in press.

I-A-16 Transient Characteristics of Antennas, R. V. Row.

Objective — To investigate theoretically and experimentally the receiving and transmitting behavior of various antennas when subject to pulse excitation.

Practical Significance — An understanding of the transient behavior of simple antennas will be of value in the practical design of large directive antennas for radar.

Status — It has become evident that the fast oscilloscope under construction has insufficient bandwidth to permit studying pulses with a rise time of $5 \cdot 10^{-10}$ sec; hence this part of the project has been discontinued. A high-speed Micro-oscillograph (G. M. Lee, Proc. I.R.E. 34, (March 1946) has been borrowed from the Research Laboratory of Electronics, M.I.T. and is now being put into operating condition.

A 20 kv impulse generator (R. C. Fletcher, Technical Reports No. XX and XXI, Laboratory for Insulation Research, M.I.T) is being constructed.

I-A-17 Properties of Single Conductor Line over a Dielectric-Coated Conducting Plane, C. Shafer

Objective — Measurement of the significant characteristics of such lines.

Practical Significance — The utilization and further application of such lines would be facilitated by a better understanding of the properties of the modes of these lines.

Status — Construction is in progress of a 4-x-8-foot ground screen formed by a single 1/4-inch sheet of dural. This construction is expected to yield the extremely flat surface required for accurate measurements. Measurements will be taken of the longitudinal and the transverse field distributions at a wavelength of 40 cm.

Consideration is being given to approximate calculations of field distribution and propagation constants, utilizing relaxation methods and by superposition of plane waves in a guide.

I-B Microwave Optics

I-B-4 Back-Scattering, R. Row, C. Tang.

Objective — The research in this project is directed toward the general study of back-scattering.

Practical Significance: A rapid and accurate method for measuring back-scattering from arbitrary obstacles is useful in determining radar cross sections.

Status: Construction of the large horizontal ground screen on the roof of the penthouse of the new laboratory has been completed. This provides a flat aluminum surface 24 1/2 x 48 ft for image-plane measurements. The working surface is made up of 1/8 inch thick 4 x 8 ft dural ft dural sheets butted together and screwed to a supporting frame of dural I-beams and channel sections, thus minimizing problems arising from thermal expansion of the sheets. This surface is accessible from the room beneath through 3 portholes (one 4-x-8-ft, and two 4-x-4-ft openings) located about its center; as well as from a flight of outside stairs. Sighting along the long dimension of the screen on the surface, the nearest interfering obstacle seen is a tree about 300 ft away.

This image plane is now available for experimental studies.

I-B-5 K-band Diffraction, C. Tang, R. Row, R. D. Kodis.

Objective: To investigate diffraction by obstacles whose dimensions are large compared to a wavelength and to extend the present knowledge of the transition from the static to optical regions in scattering problems.

Practical Significance: These problems are of interest in radar back-scattering.

Status: A horn of adjustable H-plane flare angle and length has been constructed. With this horn a noticeable improvement is obtained in approximating a uniform amplitude distribution over a limited range of a few wavelengths. The difficulty in measuring current distributions in the "shaded region" of an infinite cylinder has been overcome by matching and reducing the excessive transmission loss in the path from current probe to the feeding point in the waveguide. Steps are being taken to measure the back-scattering cross section of large cylinders.

I-B-7 Millimeter Wave Studies, R. D. Kodis.

Objective: To investigate the transmission characteristics of electromagnetic radiation in the wavelength region from 0.1 to 5 mm.

Practical Significance: An understanding of millimeter-wave transmission and the development of millimeter-wave techniques is a prerequisite to their practical utilization.

Status: A technical report on the measurement of the complex dielectric constant of polystyrene at a wavelength of 4 mm is in preparation.

1-B-9 Unflanged Semi-infinite Rectangular Guide, M. Balser, R. V. Row.

Objective — To investigate the frequency dependence of the dominant-mode reflection coefficient from the open end of an unflanged rectangular guide.

Practical Significance — An experimental measurement of this quantity is necessary as a check on an approximate theory for a previously unsolved problem.

Status — No progress has been made on the numerical computations this quarter.

Insufficient power is available from the 2K25 X-band Klystron to permit measurements of the reflection coefficient near cut-off. The measurement near cut-off, although not yet precise, will be dropped for the present and the measurements continued in the region away from cut-off.

†I-B-20 Theory of Electromagnetic Corrections to Geometrical Optics, R. D. Kodis, I. Stakgold.

Objective — The development of asymptotic expansions for scattering at high frequencies through the application of variational principles.

Practical Significance — The successful application of a general method to simple scattering problems at high frequencies may provide valuable insight into more complicated problems.

Status — A modified variational principle for the two-dimensional problem of scattering from a cylindrical obstacle has been formulated. The stationary expression involves the current distributions on the obstacle and the magnetic field on an intersecting plane parallel to the cylinder axis. The evaluation of the integrals that result from inserting "optical" distribution functions is proceeding.

Some progress has also been made in relating the correction to geometrical optics provided by variational formulations to the so-called Kirchhoff correction.

†I-B-21 The Scattering of Spherical Waves by Cylinders, D. B. Brick.

Objective — The theoretical study of the current distributions excited by a spherical wave on cylindrical scatterers of arbitrary cross section.

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†Air Force Contract AF19(604)-786.

Practical Significance: The relationship between plane wave scattering and spherical wave scattering is useful in relating experimental data to the theoretical results for cylindrical configurations.

Status: The initial problem of the scattering of the field of an arbitrarily oriented dipole by a circular cylinder is nearly complete. In addition to the work on specific cross sections, attempts are being made to formulate relationships for a cylinder of arbitrary cross section.

†I-B-22 Theoretical and Numerical Investigations of Optical Current Distributions, A. Vobach, D. B. Brick.

Objective: To investigate numerically the current distributions on cylindrical scatterers using classical and quasi-optical means.

Practical Significance: A knowledge of the behavior of the current distributions on scatterers as their characteristic dimensions and radii of curvature vary is a prerequisite to the extension of the optical and quasi-optical scattering approximations to lower frequencies.

Status: The series solutions for the current distributions on elliptic cylinders are being formulated in order to determine the range over which numerical evaluations are possible.

†I-B-23 Aperture Scattering at High Frequencies, H. Chang.

Objective: To investigate the diffraction at high frequencies of a plane electromagnetic wave by a circular aperture in an infinitely thin, perfectly conducting screen.

Practical Significance: The successful application of a general method to simple scattering problems at high frequencies may provide valuable insight into more complicated problems.

Status: Integral equations have been obtained for the polar components of the current distribution on the screen with aperture. These can be solved by the method of Wiener and Hopf if one makes use of the trigonometric approximation to the Bessel functions (valid at high frequencies). Under these conditions the current near the edge of the aperture turns out to be identical with that of Sommerfeld's solution near the edge of a half-plane, with proper polarization. By making use of this current distribution in a variational principle [1], the problem is reduced to one of evaluating some complicated integrals. This work is in progress.

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1. H. Levine and J. Schwinger, Comm. on Pure and Appl. Math., 3, 4, December 1950.

†I-B-25 Experimental Investigation of Optical Current Distributions, D. B. Brick

Objective — To measure the current distributions on large elliptical cylinders of various size and eccentricity.

Practical Significance — The experimental determination of current distributions is necessary for estimating the validity of analytic approximations.

Status — The indoor X-band ground screen and microwave anechoic chamber are being adapted for current distribution measurements on elliptic cylindrical scatterers for which the incident field is polarized perpendicular to the cylinder axis. The construction and necessary modifications are well under way. This study is being undertaken in conjunction with Project I-B-5, where the other polarization is being investigated.

I-C Microwave Circuits

††I-C-1 Tensor Permeability and Dielectric Constant of Anisotropic Media, C. L. Hogan

Objective — To measure, in the frequency range 500-24,000 Mc/s the tensor properties of media which are rendered anisotropic by an impressed magnetic field.

Practical Significance — The design of the antireciprocal elements in microwave gyrators and circulators, one-way transmission systems, etc., depends upon a detailed knowledge of the anisotropic properties of various media under influence of a steady magnetic field.

Status — Experiments are being designed to measure the tensor components of the permeability, and, in particular, the necessary equipment to make measurements at X-band frequencies has been ordered and is being assembled.

††I-C-2 Antireciprocal Elements in TEM Mode Systems, C. L. Hogan, J. Pippin

Objective — Theoretical and experimental investigation of the feasibility of building antireciprocal elements in guided wave systems propagating a TEM mode.

Practical Significance — If successful, these experiments will yield data making it possible to build antireciprocal elements in strip lines and possibly coaxial lines.

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††Air Force Contract AF19(604)-1084.

Status An approximate solution to the problem of wave propagation between parallel, infinite semiconductor planes, in the presence of a steady magnetic field has been obtained.

Experimental data have been obtained in a rectangular waveguide at K-band frequencies, using germanium as a guiding boundary.

I-D Electronics

I-D-1 Investigation of a Modified Type of Barkhausen-Kurz Oscillator, G. Kent

Objective To investigate the potentialities as a microwave power source of a Barkhausen-Kurz (B-K) tube which is especially designed to provide simple harmonic electron motion and to use efficiently the B-K energy-conversion process.

Practical Significance It is believed that a relatively high-efficiency microwave generator with frequency limitations comparable to those of the reflex klystron might be developed.

Status Some progress has been made on the construction of the low-frequency tube previously reported. Theoretical and practical aspects of the design of a 10-cm-wavelength tube are being considered.

I-D-3 Space-Charge-Wave Oscillations in the Magnetron, J. Osepchuk

Objective The experimental and theoretical study of space-charge waves in the magnetron diode.

Practical Significance The existence of evanescent space-charge waves in the magnetron diode would indicate the possibility of its use as a practical microwave generator.

Status Heater test and calibration for the dummy cathode have been completed. Final assembly of the experimental tube is under way.

I-D-4 Electrolytic Tank, P. Kennedy, G. Kent

Objective Design and construction of an electrolytic tank and associated apparatus.

Practical Significance The electrolytic tank is useful in solving Laplace's equation for two-dimensional problems or three-dimensional problems with axial symmetry, such as those which occur in electron-optical systems and other electron devices.

Status The construction of the equipment is nearly completed. A 30x30x4-ft bakelite tank and adjacent drawing board are supported in a structural steel frame. Both frame and tank can be leveled, raised, or tipped independently. A probe of adjustable height can be moved over the entire surface area of the tank by means of a system of tracks. A pen which maps the motion of the probe on the drawing board is operated electrically to plot results obtained in the tank.

A more detailed description of the apparatus will be forthcoming in a report.

I-D-11 Circuits with Nonlinear Inductance, N. S. Prywes

Objective Investigation of oscillations in circuits with nonlinear inductances.

Practical Significance The possibility of constructing frequency multipliers and high efficiency multiple frequency power supplies is indicated. Capacitive loading of magnetic amplifiers is another obvious use.

Status Experimentation as a check of theory developed is under way, and a technical report is in preparation.

I-E Random Processes

I-E-1 A Study of the Statistical Properties of Noise and Signal Waves, D. Middleton

Objective To investigate the statistical properties of various noise models, such as multiplier, partition, and Barkhausen noise, impulsive static, precipitation noise and clutter. Included also are random pulse trains and signal waves of various kinds.

Practical Applications Direct practical applications are in the field of the perception of intelligence in noise, including the factors which influence the reception and transmission of intelligence. A quantitative theory of threshold (weak signal) reception is being sought for many types of signals in interference with other than the more familiar normal statistics.

Status Further work has been done on evaluating correlation functions for "noise" signals in the broad-band and narrow-band cases.

I-E-2 Special Topics: Optimum Linear Filters for the Integration of Random Waves in Finite Time, D. Middleton, J. Storer

Objective To study the conditions under which random waves may be averaged in finite time intervals by means of linear

passive networks or filters. In particular, optimum filters for the smoothing of random functions are desired, as well as the conditions needed for such optimum integration.

Practical Applications: One direct practical application of this study lies in the reception of intelligence in the most efficient way for the always limited time at the receiver's disposal.

Status: The analytical features of a technical report have been completed; the discussion, description of results, and organization of the mathematical material remain.

I-E-3 Special Topics: Full-Wave Rectification of Noise, N. Stone, D. Middleton.

Objective: To study the effect of full-wave rectification by a ν-th power device upon an input of (a) normal random noise, (b) a sine wave and noise, and (c) noise and a signal consisting of noise. These results are to be compared with those for the corresponding half-wave problem, and are needed in the study of finite-time integration problems.

Practical Applications: A direct practical application is to the determination of the signal-to-noise ratio after processing by various nonlinear devices with inputs of (1) a sinusoidal signal in narrow-band noise; (2) a narrow-band "noise"-signal in narrow-band noise; (3) a sinusoidal signal in broad-band noise.

Status: A technical report (No. 182) will be issued shortly.

I-E-4 Rectification of Nongaussian Noise, J.A. Mullen

Objective: To obtain the quantities of physical interest when a signal and nongaussian noise are rectified.

Practical Applications: This work will make more types of noise amenable to analytic treatment and will check the sensitivity of the rectified output to the input statistics.

Status: With one or two noise pulses present, the exact answer can usually be found; and, with more pulses present, the noise characteristic function can be approximated by Pearson's and Rayleigh's methods for the random walk. With the help of this approach, the output power has been found as a double power series in the density parameter and the signal-to-noise ratio.

I-E-5 The General Theory of Reception of Signals in Noise, D. Middleton, D. Van Meter.

Objective: By formulating the reception problem in its most general terms this research seeks to show how detection and extraction

of signals may be distinguished operationally in a manner independent of arbitrary criteria of performance, and to indicate what methods of modern statistical analysis are to be used in determining optimum performance of receiving systems.

Practical Applications: The theory shows what are the best systems for a given purpose, with a definition of "best" consistent with the particular external constraints of the problem; and indicates to what degree a given practical system may depart from the ideal, permitting improvement to be related to cost in a meaningful way.

Status: During the report period a paper was prepared for publication in the Transactions of the I.R.E. and presentation at the Symposium on Information Theory to be held at M.I.T. in September. A technical report incorporating the material of this paper with additional examples and extensions of the results is now under way.

I-E-6 Study of Output Spectra of Several Nonlinear Devices when Fed by Narrow-Band Noise Plus an Unmodulated Carrier, G. Fellows.

Objective: Experimental verification of Middleton's theory on the subject, and an investigation of the problems of spectral analysis.

Practical Applications: The equipment will be used to obtain useful results for special cases of extreme computational difficulty.

Status: Experimental equipment and computations are complete. Preliminary runs show excellent agreement with theory, and final experimental procedures are therefore being initiated.

I-E-7 Experimental Investigation of the Statistical Properties of Noise and Signal Waves in FM Receivers, H. Fuller.

Objective: To extend, by experimental measurements, the theoretical results of Middleton to cases of non-ideal receiver models that are impractically difficult to treat analytically.

Practical Applications: The signal-to-noise ratio at the output of the receiver as a function of the several design parameters of an FM receiver will be determined. Together with the signal spectrum distortion this information should allow a closer approach to an optimum receiver design for a specific purpose.

Status: Computation of output spectra and correlation functions for the idealized FM receiver is nearing completion. The experimental equipment is complete with the exception of a suitable frequency modulator.

II

ELECTRON AND SOLID STATE PHYSICS

Academic Staff: Prof. J. H. Van Vleck
Prof. H. Brooks
Assoc. Prof. N. Bloembergen
Dr. F. K. Willenbrock

II-A Radio and Microwave Spectroscopy of the Solid State

A considerable number of coordinated investigations of nuclear and electronic spin resonance in various types of solids are intended to result in a better understanding of the structure and behavior of magnetic spin systems and of the nature of crystalline imperfections in solids.

II-A-1 Nuclear Resonance in Metals and Alloys, T. J. Rowland and N. Bloembergen

Objective To obtain information about electronic structure and diffusion in pure metals and alloys by measuring nuclear resonance line shapes, widths, and shifts as functions of concentration of various solute metals, field strength and isotopic concentration. Quadrupole effects in metals are also being investigated.

Status Data on the five different isotopic compositions (see P.R. 31) of thallium in thallic oxide and in metallic thallium are being accumulated. Each absorption is being measured at field strengths of about 6000 and 3000 gauss in order to determine the field dependence of the line widths. The resonance line of Tl^{205} varies from about 10 kc/s in Tl_2O_3 enriched to 98.7 Tl^{205} to greater than 50 kc/s width in Tl_2O_3 of only 10 Tl^{205}. The Tl^{203} line behaves similarly, becoming narrower in Tl^{203} enriched samples of Tl_2O_3.

The work on other metals and alloys previously described under this project has been completed and a final report is being prepared.

II-A-2 Nuclear Magnetic Relaxation in Metals, Alloys, and Semiconductors, A. G. Redfield

Objective To obtain the nuclear magnetic relaxation time in metals, alloys, and semiconductors by measuring the nuclear magnetic resonance line shape as a function of applied radio-frequency power.

Status The spin lattice relaxation times in aluminum and copper have been measured with standard steady-state saturation techniques, using previously described equipment. For

pure aluminum, T_1 is 2.2 + .5 ms; for annealed copper it is about 2 ms. These values are consistent with the Korringa relation and Knight shifts which predict T_1=5.1 ms for Al and 2.3 ms for Cu; the discrepancy in aluminum may be due to p-character of the electronic wave function. For cold-worked copper and Al-Zn 30.2% alloy, in which only the central component of the resonance line is observable, the relaxation times are the same as for the pure metals within experimental error, in agreement with a simple theory based on the assumption that due to the quadrupole interaction only spin-spin collisions between nuclei with $m = \pm 1/2$ are allowed.

An unexpected feature of these observations is the fact that the dispersion χ' (real part of the nuclear paramagnetic susceptibility) does not decrease on saturation as predicted by the Bloch equations, but remains of the same order of magnitude until the r-f amplitude H_1 approaches ΔH, the dipolar line width. In aluminum, the derivative of the dispersion at resonance actually increases as H_1 is increased, for $\Delta H < H_1$, while in copper it is roughly constant. For $H_1 \gg \Delta H$, the dispersion behaves in roughly the same way as in a liquid above saturation, and is of the same order of magnitude.

These observations can be explained qualitatively for $H_1 < \Delta H$ and quantitatively for $H_1 >> \Delta H$ by applying a canonical transformation to the spin Hamiltonian corresponding to a precessing coordinate system transformation.[1]. The resulting Hamiltonian contains terms with $e^{i\omega t}$, $e^{2i\omega t}$ time dependences, where ω is the applied frequency. These terms can be ignored since they do not represent a secular perturbation of the time-independent term of the new Hamiltonian. At resonance the time-independent term of the Hamiltonian is similar to the untransformed spin Hamiltonian, except that H_1 replaces H_0 and the spin-spin interactions are about half as large. Consideration of this Hamiltonian leads to detailed predictions concerning χ' for $H_1 >> \Delta H$ and indicates that the behavior for $H_1 < \Delta H$ is a reasonable consequence of the spin-spin interaction. It is also concluded that the term $u/|\gamma|H_1 T_2$ in the Block equations[2] is grossly incorrect above saturation because energy $\hbar \gamma H_1$ per spin is required for the decay represented by this term. T_2 must be replaced by a spin lattice relaxation time T_1 in this term.

Finally, it has been predicted and observed that for large H_1, the dispersion signal can be reduced by the application of an audio-frequency magnetic field in the direction of the steady field H_0. The reduction is a maximum at the nutation frequency γH_1. By measuring χ' as a function of the audio-frequency field T_1' can be determined, and by measuring the audio-frequency dependence of the effect it may be possible in some cases to obtain information about the source of the broadening of the nuclear resonance line. The effect is theoretically treated most simply in a precessing coordinate

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1. Rabi, Ramsey, and Schwinger, Rev. Mod. Phys. 26, 167 (1954).
2. F. Bloch, Phys. Rev. 70, 460 (1946), equation (42a, b, c). u is the component of magnetization in the rotating coordinate system along H_1, the rotating r-f field (dispersion mode).

system, and is closely analagous to ordinary nuclear resonance saturation, with H_1 playing the role of H_0, the audio field playing the role of H_1, and χ' corresponding to M_z. The audio-frequency dependence of the effect can be treated with a diagonal sum method.

II-A-3 Nuclear Magnetic Spin-Spin Relaxation, K. Dwight.

Objective To measure spin-spin relaxation times in systems of nuclear magnetic dipoles when energy is absorbed at audio-frequencies in weak external magnetic fields.

Status Work was continued on the new low-temperature equipment described in our last report. The shelves, transit, and positioning mechanisms have been assembled and tested. Parts that proved unsatisfactory have been redesigned and remade and they now perform adequately.

A calibrator circuit was added to the r-f oscillator. The oscillator was also partly rebuilt in order to minimize stray capacitance, so that a larger search coil could be used. Indeed, we found that the number of turns could be double that used before.

The audio-frequency coils were also built, and were calibrated. The sample holder has been built, but has not been tested at liquid-nitrogen temperature. The special dewar proved unsatisfactory. It was remade for continuous pumping, without much success. A leak has finally been located, and is now being dealt with.

II-A-4 Nuclear Magnetic Resonance in Imperfect Crystals, N. Bloembergen.

Objective To study crystalline imperfections using nuclear magnetic resonance techniques.

Status A general survey has been made of the effects of crystalline imperfections on the nuclear magnetic resonance. Dislocations, vacancies and interstitials, foreign atoms, electrons and holes, phonons and excitons have been considered, and the internal magnetic and inhomogeneous electric fields around them which interact with the nuclear magnetic dipole and electric quadrupole moments, have been analyzed. A technical report (T.R. No. 199) has been completed and is in press.

II-A-10 Paramagnetic Resonance in Impurity Semiconductors, F. K. Willenbrock.

Objective To measure the paramagnetic resonance due to the unpaired electron spin of impurity atoms in n- and p-type semiconductors. From this measurement, the g-factor and spin-lattice relaxation time of the electrons and holes can be determined.

Status The major effort on this project during this period has been in improving the frequency-multiplier circuit which is used for the accurate determination of the frequency of the microwave oscillators.

II-A-11 Paramagnetic Resonance in Alkali Metals, R.H. Silsbee.

Objective To study the magnetic resonance of the conduction electrons in colloidal particles of alkali metals in alkali halide crystals.

Status The automatic frequency control (AFC) system mentioned in Progress Report No. 31 has been constructed, tested, and is now in use. It has been found necessary to use bracing to reduce mechanical vibrations of the microwave circuit. A rough estimate of the sensitivity indicates that the apparatus is now capable of detecting the resonance of 10^{14} spins at room temperature with a line width of 10 gauss, and it is expected that the sensitivity can be improved further.

A sodium-chloride crystal, prepared last fall, is now being run in an effort to find the conduction spin resonance.

II-A-20 Ferromagnetic Resonance in Single Crystals of Nickel, Cobalt, and Nickel Ferrite, C.J. Hubbard.

Objective To obtain the ferromagnetic resonance line width in single crystals of nickel ferrite ($NiO \cdot Fe_2O_3$) at various temperatures down to 4^oK, at frequencies in the 1 cm region. Other substances are to be studied later.

Status The recently rebuilt electromagnet has been calibrated by the nuclear resonance technique, yielding satisfactory fields.

A spherical single crystal of $NiO \cdot Fe_2O_3$ was oriented by X-ray, and investigated in the transmission-type cavity that has been described. For the sample size employed, the resonant absorption was so great as to require more sensitive detection apparatus than is conveniently available. Also, the associated dispersion exceeded the bandwidth of some of the microwave components. For this reason a smaller sample has been prepared, approximately .010 m in diameter, and oriented by X-ray. It will be investigated, along with a series of smaller samples that are being prepared.

A considerable amount of time has been spent in conjunction with C. Maynard (Project II-B-3), in the preparation of a liquid helium cryostat and associated vacuum system.

II-B Properties of Electrons in Solids

Several investigations, using widely different experimental techniques, are all concerned with the behavior of electrons in metals and semiconductors. They include the measurement of Hall effect in ferromagnetic materials, electronic spin specific heat, magnetoresistance and properties of semiconductors under hydrostatic pressure.

II-B-1 Hall Effect in Ferro- and Ferrimagnetics, J. Lavine.

Objective To investigate some of the electrical and magnetic properties of ferrites by means of the Hall measurement. The purpose of the measurement is to obtain information about the conductivity mechanism in ferrites.

Status The main effort during this report period has been the measurement of R_1 and the resistivity in a series of Ni alloys between room temperature and liquid-air temperature. These alloys ranged from ~99.8% to 95% Ni. In no case did R_1 vary as ρ^2 as required by the Karplus-Luttinger theory. R_1 varied as $\rho^{1.48}$ for the purest alloy, and as $\rho^{1.20}$ for the 95% Ni alloy.

Measurements of R_1 were made on a sample of ferrite grown by Linde Air Products. This sample, stated to be $(NiO)_{.75}(FeO)_{.25}Fe_2O_3$, displayed a curve of R_1 vs T characteristic of Fe_3O_4 (P.R. No. 31, Fig. III-4). At room temperature, R_1 for $(NiO)_{.75}-(FeO)_{.25}-Fe_2O_3$ is about four times larger than R_1 in Fe_3O_4. R_1 in this sample changes sign at about 410°C compared to 380°C for Fe_3O_4. Although the resistivity of $(NiO)_{.75}(FeO)_{.25}Fe_2O_3$ does not increase above room temperature as does Fe_3O_4; nevertheless, there appears to be no obvious relation between R_1 and ρ in this ferrite.

R_o has been measured on the sample $(NiO)_{.75}(FeO)_{.25}(Fe_2O_3$ and will be reported at a later date.

II-B-2 Specific Heats of Spin Wave Systems, J. S. Kouvel.

Objective To determine the spin wave contributions to the specific heats of ferrimagnetic and antiferromagnetic materials at liquid helium temperatures.

Status A liquid helium run was attempted with the calorimeter placed in the liquid helium reservoir of an existing cryostat (which, having been designed for work in a magnetic field, has a long, narrow "tail" extending down from the reservoir). Although the end of liquid helium transfer tube is prevented by the calorimeter from going below the bottom of the reservoir, it was hoped that the resulting increased loss of liquid helium in transferring it into the cryostat would be compensated by the immediacy of use of this cryostat. Unfortunately, the loss of liquid helium in splashing against the bottom of the reservoir and trying to flow down and cool the "tail" of the cryostat, was found to be excessive. Hence, a new cryostat has been designed with a liquid helium container in the form of a long thin-walled stainless steel cylinder, into the very bottom of which the calorimeter will be suspended. The construction of this cryostat is now in progress.

A technical report (No. 198) entitled, "Some Spin Wave Properties of Ferrimagnetic and Antiferromagnetic Simple Cubic Crystals," has recently been issued. It incorporates our theoretical work on thermal and magnetic spin wave properties of these somewhat idealized structures at low temperatures. From a similar point of view, we are now studying the spinel structures of the ferrites.

II-B-3 Magnetoresistance in Strained Metals, C.W. Maynard.

Objective To investigate the change in resistance of metals at the temperature of liquid helium when subjected simultaneously to a magnetic field and to a strain.

Status During the first attempted experiment with the cryostat, difficulties were encountered from too rapid evaporation of the liquid helium. A second test was made with no experimental apparatus in the cryostat. The evaporation rate still proved to be excessive. This is believed to have been due to a poor vacuum and possibly to a bending of the inner helium chamber in such a way as to touch the liquid-nitrogen jacket. A nylon, knife-edged spacer has been placed between inner and outer chambers of the cryostat to prevent this bending. New vacuum valves and gauges have been installed to improve the vacuum system and to provide a better check on the operation.

The electrical measuring system for the magnetoresistance experiments has been changed. The Kelvin Bridge which we had originally planned to use has been discarded since the heavy low-resistance wiring required would introduce large conduction paths for heat into the cryostat. Further, the wiring resistance would introduce uncertainties in the balance conditions for the bridge. The new system is a potentiometric null method which eliminates both of the above difficulties. The necessary equipment for this change has been obtained.

II-B-4 High-pressure Effects in Semiconductors*, W. Paul and H. Brooks.

Objective To investigate the electric, magnetic and optical properties of semiconductors at pressures up to 30,000 kg/cm^2.

Status Parts of this project are being carried out in collaboration with Group 35, Project Lincoln, at M.I.T. Extensive use is being made of the facilities available in Professor Bridgman's laboratory.

a. Measurement of Hall Constant and Magnetoresistance**

The measurements on the Hall constant and magnetoresistance of oriented samples of p-type germanium and of p-type silicon have been continued. A

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*This is a coordinate program largely supported and partially staffed by Lincoln Laboratory.

**In conjunction with G. B. Benedek of Group 35, Lincoln Laboratory.

satisfactory temperature bath has been built to maintain the pressure bomb at 0°C when it is between the magnet poles. The measurements on p-type silicon indicate that there exists long-time trapping at 0°C.

The change in the trapped carrier density on altering pressure produces changes in the conductivity comparable with those due to mobility variations, and ways are being explored either to estimate this trapping effect independently, or to procure some silicon samples where the trap density is small compared with the conduction carrier density. The time for emptying these traps agrees qualitatively with that found for deep traps in p-type silicon by Haynes and Hornbeck[1]. The measurements on p-type germanium at 0°C show that for a sample cut so that all faces are (100), the transverse magnetoresistance coefficient decreases by some 11% for 10,000 kg/cm^2 pressure. It will be recalled that in p-type germanium the drift mobility increases under pressure by 2% in this pressure range, and the Hall mobility decreases by 2%.

A Be-Cu cylinder of 2 1/4 in. o.d., 5/16 in. i.d. has recently been tested with lead-indium as pressure transmitter, to a top pressure of 28,000 kg/cm^2. The cylinder hole expanded by some 0.017 in. on the first pressure application, but did not expand again on a second run. Tests are now being made on the same cylinder using a true liquid as pressure transmitter. The aim is to establish the possibility of constructing a Be-Cu bomb safe to 25,000 kg/cm that can be used in magnetic experiments.

b. Measurement of the Optical Properties*

(1) The last report indicated that Freon 113, supplied as a liquid, had replaced CS_2 as our pressure transmitting fluid since it has complete optical transparency in the infra-red and is unlikely to freeze at low pressures. Freon 113 was tested for a change of phase in the pressure range from 2000-9000 kg/cm^2. None was found. Accordingly tests were attempted on the absorption edge shift in silicon, using Freon 113 as transmitter together with the sample-raising device mentioned in the previous report. At a manganin gauge reading corresponding to nearly 8000 kg/cm^2, the slim piston of this sample-raising device shattered, causing severe damage to the holder, the sample and the bottom sealing plug of the bomb. The apparent explanation was that the slim (3/32 in.) piston had become slightly cocked in its guide hole and had sheared across when being raised in the course of the test. More recent tests on Freon 113 at lower pressures have shown, however, that around 1200 kg/cm^2 the Freon changes phase (presumably to the solid) and an abrupt change takes place in the light transmitted through an apparatus filled with the liquid. This decrease in transmitted energy (essentially nonselective) is, at the moment, thought to be caused by scattering from the forming Freon 113 crystals.** It has also been found that repeated applications of pressure to the apparatus, without dismantling, decrease the changes in transmitted energy that normally take place during a pressure run. This must mean that the sapphire windows, which still bend

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1. Haynes and Hornbeck, Phys. Rev. 90, 152(1953); Bull. Am. Phys. Soc. 29,40 (1954).

*In conjunction with R.L. Powell and D.M. Warschauer, Group 35, Lincoln Laboratory.

**The piston shattering is therefore attributable to the forcing of the piston into solid Freon 113.

through slots in their steel supports when pressure is applied, and act as lenses, are settled into a quasi-stable position by the first pressure applications, and remain set for later applications.

(2) Measurements of the transmitted energy at 8 microns have been made on crystals over a temperature range from close to liquid-nitrogen to well above room temperature. The same temperature bath is used over the entire range. The variation of transmitted energy follows, at least qualitatively, that deduced from the known temperature variation of mobility in the sample. We are now engaged in measuring the change in absorption coefficient of the sample.

II-C Topics in the Theory of the Solid State

This program includes a number of subjects in the quantum theory of solids, many of which are closely related to the experimental program and supplement it. The various investigations include the theory of the cohesive energy and elastic constants of metals, the theory of impurity and imperfection wave functions in semiconductors and metals, and the theory of electrical resistivity as a function of pressure in metals.

Cohesive Energy of the Monovalent Metals

Work has been completed on the application of the quantum defect method to the calculation of the energy eigenvalues at various symmetry points of the Brillouin zone in sodium for comparison with earlier calculations. For satisfying the boundary conditions the method of Howarth and Jones has been used, modified by a more extensive and accurate use of the surface correction integral. In general the present calculations agree fairly well with the earlier work of Howarth and Jones on sodium. The principal difference lies in the predicted energy gap at the position N of the Brioullin zone. H and J predicted an energy gap of 0.65 ev, whereas the present work gives practically a vanishing gap. There is reason to believe that the result of H and J arises from the fact that they did not employ the surface correction integral rather than from differences between their wave functions and the ones obtained from the quantum defect method.

A difficulty in the cellular method arises from the extension of the 1/r potential out to the face of the cell. It can be shown that the conventional expansion of the Bloch wave function in spherical harmonics is not, in fact, convergent on any sphere out to that which circumscribes the unit cell, but only converges on the largest sphere which does not intersect any of the circumscribed spheres from neighboring cells. The result of this condition is that even though the empty lattice test gives good bunching of eigenvalues for different point boundary conditions, the bunching is not nearly so good in the case of the actual atomic potential. In consequence, the coefficients of the higher spherical harmonics in the expansion of the wave function are very

large and very sensitive to which point boundary conditions are used. In spite of this the eigenvalues obtained by means of the surface correction integral using the wave functions from any of the point boundary conditions bunch very well, indicating that final results are reliable provided the correction integral is always used.

The above difficulty could be overcome in the following way. Since the atomic potential is quite artificial in the outer reaches of the cell anyway, it seems wisest to replace it by a potential which is constant outside the largest sphere of convergence (see above). For this particular case the effective potential remains spherically symmetric right out to the circumscribed sphere, and the expansion in spherical harmonics is therefore convergent. The wave functions are spherical Bessel functions in the outer region. This procedure has not yet been attempted.

In the course of this work a start has been made at computing more extensive tables of the Coulomb wave functions than were given by Kuhn. These are being prepared to permit five-place accuracy for regular functions for $\ell = 8$ and the irregular functions for $\ell = 0$. The recurrence relations can then be used to compute the functions for intermediate ℓ with comparable accuracy.

The arguments for the validity of the quantum defect method have been systematized so that this procedure is now on quite a firm theoretical foundation. (F. Ham) [1].

Calculations on the three noble metals have been completed. The main improvement in results since the last progress report has been the adoption of Brooks' suggestion regarding the use of core eigenvalues in improving the extrapolation of the quantum defect for p-terms, and in the use of the η-extrapolation instead of the δ-extrapolation for p-terms. The corrections for non-Coulombic field at the cell radius were made rather crudely. The potential seen by the valence electron was chosen to have the form of the Hartree-Fock potential for Cu, but with the radial scale adjusted so that the repulsive potential would give the observed lattice spacing in each case. The logarithmic derivatives of the radial wave functions were then corrected by the perturbation method proposed by Brooks. The results are shown in the accompanying table. The values for the cohesive energy are upper limits, since the repulsive energy is not included. The calculation includes (1) the lowest energy of the valence electron, (2) the Fermi energy calculated with the η-value computed from the p-functions, (3) the free electron values of Coulomb, exchange, and correlation energies for the appropriate electron density.

It is noteworthy that the effective mass is so closely equal to the free electron mass in all three cases. For Cu this is in agreement with previous results of Jones.

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1. Physics Department. Not directly supported under Project 1. However, computing facilities of Project 1 have been utilized in connection with preparation of tables of the Coulomb wave functions.

Metal	Calc Cohesive Energy (kcal/mol)	Obs	$a = m/m_{eff}$
Cu	61	81	0.99
Ag	56	68	1.00
Au	49	92	0.99

It must be emphasized that this calculation is extremely crude in comparison with the corresponding calculation for the alkalis, because many of the assumptions are not very well satisfied. (K. Kambe) [2].

Resistivity of the Alkalis

A number of factors have been investigated to try to explain theoretically the pressure dependence of resistivity in the alkali metals. The following possibilities have been rejected on the basis of quantitative calculations:

(1) The effect of the p-part of the Bloch function on the matrix elements for scattering.

(2) The effect of the very large elastic anisotropy in the alkalis.

(3) The influence of effective mass differing from free electron mass on the density of states at the Fermi surface.

(4) Inadequacies in previous theories of the "umklapprocez," especially the treatment of the shielding factor.

All of these influences affect the results, but the changes resulting from them appear to be mutually cancelling, so that the final answers differ but little from the original work of Bardeen. The same statement also applies to the absolute magnitude of the resistivity, which theory gives as too low. (M. Bailyn, H. Brooks) [3].

Magnetic Properties of Conduction Electrons

The η-extrapolation method, mentioned in the last progress report in connection with the quantum defect method, has been extended to the extrapolation of the fine structure for the calculation of the g-factor for the alkalis. All difficulties of previous extrapolation methods for the fine-structure have been removed. (H. Brooks)

Semiconductor Theory

A complete proof of the equivalence of the Wannier and Green's function procedures for impurity wave functions has been worked out. The Green's function procedure, which is quite general, can be applied to more complex band structures. A start has been made at investigating the case of a localized impurity (disturbance in potential confined to one cell of a monatomic lattice) with a level within a narrow-band gap, so that both band edges have to be taken into account. (N. Fletcher, H. Brooks) [3]

2. Work supported by Project 1. Dr. Kambe has returned to Japan.
3. No direct support of Project 1.

Nuclear Quadrupole Resonance

A technical report, No. 198 has been issued, entitled "The Nuclear Quadrupole Resonance and Crystal Structure of Solid Iodines," an abstract of which appears on p. A-1 of this report. (K. W. H. Stevens).

II-D Electron Physics

II-D-1 Field-Emission and Work Function of Germanium, F. Allen

Objective To study the field emission from single germanium crystals in a Müller-type field-emission microscope. Information on surface contaminants, work function and electron energy levels at or near the surface may be obtained, thus contributing to the understanding of semiconductor phenomena involving surfaces.

Status The auxiliary program of measuring contact potentials of the various faces of single germanium crystals by the Kelvin method in high vacuum is well under way. Two runs have been made measuring (a) the contact potential difference between a polycrystalline Mo surface and various crystal faces of a single Ni crystal, and (b) the c.p.d. between the 110 face of a single Ni crystal and the 110 and 111 faces of a single Ge crystal of $\sim$ 25 ohm-cm resistivity. Vacua on the order of 5×10^{-9} to 5×10^{-10} mm.Hg. have been used, and surfaces have been cleaned by heating to temperatures near the melting point by electron bombardment for the metals and by ohmic a-c heating for the Ge. Stability and reproducibility of results suggest that the surfaces studied are either perfectly clean or, at most, are contaminated with a few monolayers of stable oxides.

For the Ni crystal the work function of the 110 face was found to be 0.20 ± 0.05 ev higher than that of the 100 face and equal to that of the polycrystalline Mo reference surface within ± 0.1 ev. For the intrinsic Ge sample the 110 face had a work function only 0.05 ± 0.02 ev higher than that of the 111 face and 0.20 ± 0.05 ev lower than that of the 110 Ni reference face.

II-D-2 Properties of the Magnetron Diode at Microwave Frequencies, J. Bradshaw.

Objective To study the behavior of the space charge in a cylindrical magnetron diode and its performance at microwave frequencies. Additional theoretical and experimental work is needed to determine the space-charge distribution.

Status Work under this project has been terminated. Two Technical Reports, No. 185 entitled "A Probe Signal Study of the Hall Magnetron Diode," and No. 201, entitled "The Distribution of Space Charge in the Hall Magnetron Diode," both based on work done under this project, are being prepared.

III

WAVE PROPAGATION

Senior Staff: H. R. Mimno
J. A. Pierce

Project III-1 Study of Ionospheric Abnormalities

Research Staff: K. Toman, D. Davidson, J. A. Pierce, J. C. Williams

Objective In the study of upper-atmosphere characteristics, radio reflections due to the passage of meteors, the occurrence of auroral displays, and the presence of sporadic ionization are of considerable interest.

Status

E-Region

Recording on 3.5 Mc/s was discontinued on June 30, 1954 as this frequency is no longer available for experimental use. After considerable monitoring and subsequent negotiation, we have secured an authorization from the FCC for the frequency 3.243 Mc/s. Transmissions on this new channel were started on July 14.

A study of the 3.5 Mc/s records for the last six months shows very few moving clouds of sporadic ionization. This is in line with the connection, which our analysis is beginning to show, between periods of high magnetic activity and occurrence of moving sporadic clouds. The sunspot cycle is now in its trough, and there have been no major magnetic storms in 1954 to date. (There has also been very little auroral activity, and therefore North Atlantic short-wave transmission has suffered hardly at all.) In contrast, this summer shows an extraordinary amount of M-type (multiple hop, opaque) sporadic E-layer activity; this is in the nature of a sheet of ionization covering very large areas. Its production is normally at a maximum during summer months in the middle latitudes. It appears not to be dependent on terrestrial magnetic activity or solar sunspots for its generation.

F-Region

The cross-correlation analysis of the 3.5 Mc/s transmission delay records of the F_1 region during the period between August 1952 and December 1953 resulted in the finding of an average speed of 361 km/h (100 m/s) and a 50% median value of 392 km/h (109 m/s) for mid-day data. The annual variation of the speed of movement of the F_1-region seems to follow the annual variation of the virtual height of this region with a maximum in winter and a minimum in summer. Unlike the annual period of the speed of movement, the direction of movement has a semi-annual period with maximum deviation east of north around the equinoxes.

Until the proposed station in the Monadnock area can be put into operation (P.R. 30,31) a 3.5 Mc/s receiving system has been set up temporarily in Cambridge. A carbonized cable-splice, feeding the transmitter in Concord, as well as a required change of frequency (from 3.5 Mc/s to 3.24 Mc/s) resulted in minor delays.

Project III-2 Fixed-Frequency Ionospheric Study

Research Staff: J. A. Pierce, J. C. Williams, D. Davidson

Objective For the study of the ionosphere by pulsed radio signals, several types of equipment are required. The timing of the transmitter is controlled by a stable crystal oscillator and a chain of frequency-dividers. The received signals are displayed as intensity modulation on a fast, triggered cathode-ray trace, which is photographed on continuously moving paper. The problem of maintaining synchronization between the triggering of the fast trace and the reception of the signal from a distant transmitter has been solved in two ways. If the oscillators which control the repetition rates of the distant transmitter and the trace generator of the local oscilloscope are sufficiently stable, synchronization can be maintained manually. Oscillators capable of such stability have been built and described under Project III-3. A more elaborate method makes use of a sky-wave synchronizer which automatically controls the frequency of the local oscillator to maintain synchronization with the received sky-wave signal. The development of the sky-wave synchronizer and associated equipment is the subject of this project.

Status Recordings of the Nantucket signal are continuing.

Project III-3 An Oscillator of Unusual Long-Term Stability

Research Staff: J. A. Pierce

Objective Crystal oscillators of exceptional stability provide a simple method of maintaining synchronism between a distant pulse transmitter and a local recording oscilloscope for the study of long-distance propagation. For this purpose the local oscillator is adjusted manually with as much precision as possible to the same frequency as the distant oscillator. If the oscillators are sufficiently stable, they will not differ after a day or so by more than a part in 10^8.

Status A further improvement in recording WWV and MSF has resulted from the construction of a rudimentary constant-temperature vault to house our oscillators. This small room is at the basement level and is in contact with the earth on four surfaces. It will probably show an annual variation of several degrees, but the total diurnal variation in temperature is considerably less than a tenth of a degree. One oscillator has been installed in the room for a few days and the prognosis is good. The total drift in frequency for the past 24 hours, with respect to WWV, was barely measurable; about two parts in 10^{10}.

Project III-4 Studies of Transmission Time and Absorption in an Atmosphere of Varying Refractive Index

Research Staff: Mrs. E. H. Moritz, J. A. Pierce

Objective The purpose is two-fold: (1) to improve current methods of eliciting from a vertical-incidence ionospheric sounding, information concerning oblique sky-wave transmission, such as maximum usable frequency, skip distance, etc., and (2) to utilize oblique-incidence relations in obtaining from the records of Project III-2 further information regarding electron distribution in the ionosphere and its effect on transmission time and sky-wave signal strength.

Status Not enough time has been spent on the Noise Survey to complete the drawing of contours, as we hoped to do by this time. Substantially all the data, however, have been reduced to final tabular or graphical form and a few more days of plotting should complete the reduction.

The patterns of noise observed differ from those anticipated. They show (in terms of average noise energy) relatively little change in level from Southern Texas to Winnipeg but a drop of about 10 decibels in moving east or west to Ottawa or Bainbridge. The greatest noise appears to be in the latitude of Oklahoma or Kansas with a definite drop at more southerly sites amounting to some 4 decibels at the Canal Zone. At the extreme northern end of the chain (at Resolute Bay) the noise is less than that in Kansas by some 20 decibels at 15 kc and by 40 decibels at 180 kc.

Project III-5 Carrier-Frequency Phase Studies

Research Staff: J. A. Pierce

Objective To exploit some of the possibilities of coherent detection at low radio frequencies. By utilizing the inherent phase stability of transmission at these frequencies, field strength can be measured well below the ambient noise level and new data on transmission time can be collected.

Status The carrier phase studies received a big bonus on June 2, when GBR, the 16 kc outlet of the British Post Office at Rugby, was changed so that its carrier frequency is now derived from the primary standard at the National Physical Laboratory. Except that there is no definite schedule of transmissions, GBR thus has become the best source of standard frequency for reception at long distances.

On July 11 GBR was transmitting for a large part of the day and an excellent record was obtained, a part of which is shown in Fig. III-(1). This figure shows a little less than one r-f cycle (61 μs) in the vertical dimension and some 14 hours horizontally. For one hour the record was switched to 60 kc for the regular MSF transmission that resulted in about four cycles showing on the record.

The sensitivity of this scale is such that a slope corresponding to the diagonal of Fig. III-1 would indicate a frequency difference (between our oscillator and GBR) of about 1.2 parts in 10^9. Throughout much of the record shown the agreement is of the order of a part in 10^{10}.

In Fig. III-2, deviations in phase of the incoming signal for this date have been plotted with the average slope removed. The result is a curve of the diurnal variation of apparent time of arrival. The variation shown, about $\pm$ 30 μs, is made up of three factors:

1. Diurnal variation in the frequency of our oscillator, assuming none for GBR (note: this oscillator was not in our newly-controlled ambient temperature environment).

2. Actual variation in the transmission time of the signal from Rugby.

3. (Possibly) Phase changes due to temperature detuning of the receiver.

Thus, no immediate conclusions can be drawn about the diurnal variation of transmission time. The important point is that the curve is smooth except for fluctuations almost certainly due to transmission vagaries at about 0230 EST and about 2200 EST. In both cases the magnitude of the phase fluctuation is about $\pm$ 3μ s or $\pm$ 20 degrees of phase.

We confidently expect that further work will establish the magnitude of the true diurnal variation in transmission time. It will certainly lead to a good figure for the statistical uncertainty.

Project III-6 Nonvertical-Incidence Sweep-Frequency Measurements

Research Staff: H. R. Mimno

Objective Harvard University has developed a vertical-incidence ionosphere-sounding device of novel and unique design, which automatically plots a logarithmic "sweep-frequency" record by quickly scanning 100 discrete frequencies, each individual frequency being crystal-controlled at the pulsed transmitter and at the local oscillator of a wholly separate receiving unit. Demonstrated advantages of this new method suggest the desirability of extending it to include simultaneous nonvertical measurements.

Status Authorization for procurement of protective shelters having been received on May 17, 1954, preparations for continuation of the research are satisfactorily under way.

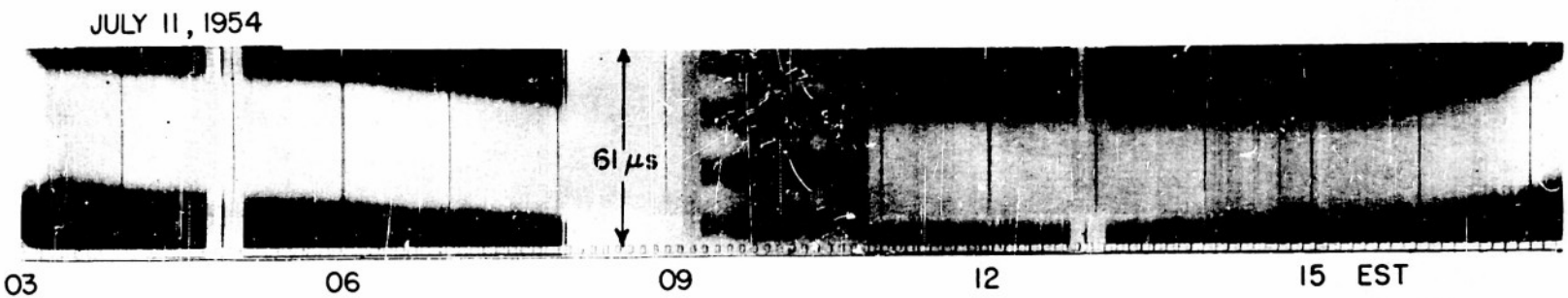

FIG. III-I VARIATION OF THE RECEIVED PHASE OF THE CARRIER OF GBR (16 kc) RECEIVED AT CAMBRIDGE. BETWEEN 0930 AND 1030 THE RECORD SHOWS MSF, THE 60 kc. STANDARD FREQUENCY STATION ALSO AT RUGBY

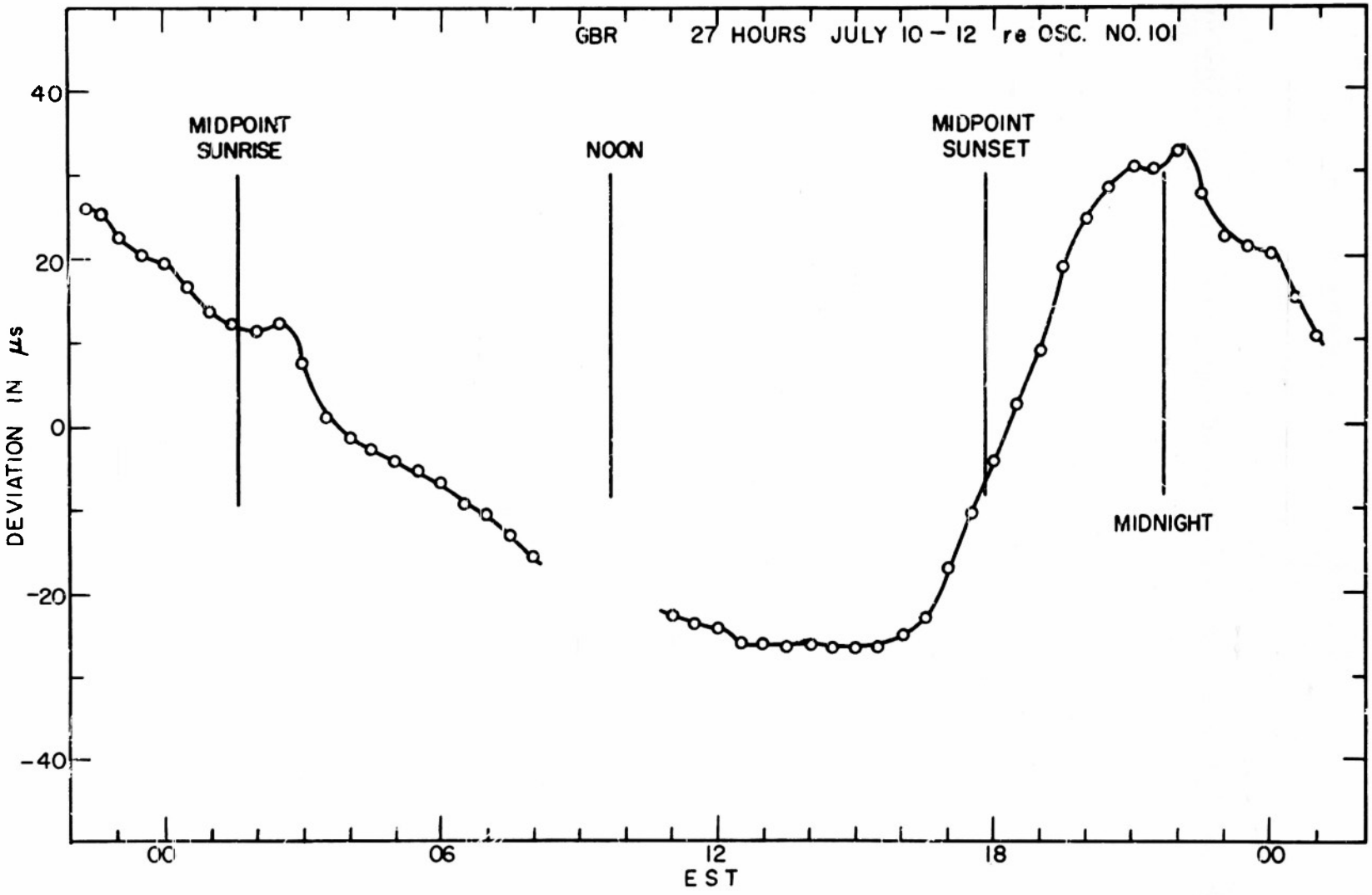
GBR 27 HOURS JULY 10 – 12 re OSC. NO. 101
MIDPOINT SUNRISE
NOON
MIDPOINT SUNSET
MIDNIGHT
DEVIATION IN μs
40
20
0
-20
-40
00
06
12
18
00
EST

FIGURE III-2

Abstracts of Technical Reports

(Completed since April 1, 1954)

The Collinear Antenna Array with a Section of Two-Wire Line as Coupling Element

Charles C. H. Tang

Technical Report No. 196

The problem of a symmetrical three-element collinear antenna array with a section of two-wire line as the coupling element between antennas is studied in order to obtain qualitatively the conditions under which the currents in the parasites are in phase with the currents in the driven antenna. The phase of the currents in the parasitic elements is reversed only when (1) the over-all length of the section of two-wire line and the parasite is near an odd integral multiple of a quarter-wavelength, and (2) the position of the short-circuiting bar or tandem bridge on the section of line is about a quarter-wavelength away from the array. The reversal of the phase of the current on the parasite is independent of the length of the driver, but the length of the driver is involved in the driving-point impedance. The current on the array as a whole can be decomposed into a main antenna current and a secondary antenna current. The main antenna current due to the driving voltage is excited on the driver and the two-wire line, while the gap voltage produced indirectly by the main antenna current is responsible for the secondary antenna current on the driver and parasite. It is the secondary antenna mode that causes the reversal of the phase of the current on the parasite. The radiation field of the array as a whole is a superposition of the two fields produced respectively by the current on the two-wire line and that on the driver and parasites.

The Nuclear Quadrupole Resonance and Crystal Structure of Solid Iodine

K. W. H. Stevens

Technical Report No. 197

Previous attempts to explain the anisotropy of the quadrupole resonance in solid iodine are critically reviewed and an attempt is made to set up a valence bond description of the iodine molecule which contains the possibility that additional weak bonds are formed in crystalline iodine. This is primarily accomplished by introducing d-hybridization. The observed bond angles are then used to estimate some of the parameters in the orbits. Use is made of knowledge about nuclear quadrupole interaction in solid I_2 and in the iodine atom to determine further parameters, and in this way a picture of the iodine molecule and its behavior in a crystal is obtained. An interesting possibility which then arises is that the lobes of the wave function of different iodine

molecules do not overlap very strongly because a maximum of one molecule seems to be directed towards a minimum of another. This does not correspond to the usual ideas about bonds, but as the theory passes smoothly from the notion of maximum overlap to this new situation, no discussion is given about how it should be described. It is also seen that the observation of the quadrupole resonance in single crystals of iodine (if this becomes possible) would provide very useful information and checks on the theory.

Some Spin Wave Properties of Ferrimagnetic and Antiferromagnetic Simple Cubic Crystals

James S. Kouvel and Harvey Brooks

Technical Report No. 198

The model whose "bulk" spin wave properties (i.e., the temperature variation of the magnetization and of the spin specific heat) at temperatures very low compared to the Curie temperature, are derived semi-classically in this paper, is a simple cubic single crystal consisting of two magnetic spin sublattices. Due to nearest-neighbor negative exchange interaction between the sublattices, their associated spin vectors tend to be oppositely directed. Hence, when the magnitudes of the spin vectors of the two sublattices are unequal, the structure is ferrimagnetic, and when they are equal, the structure is antiferromagnetic. The magnetization and spin specific heat of the former are found to follow a $T^{3/2}$ law (similar to the results of previous investigations of ferromagnetics) while the spin specific heat of the latter is found to vary as T^3. The effects of magnetic anisotropy, externally applied magnetic fields, and next-to-nearest neighbor exchange interaction, on these properties are also considered.

Nuclear Magnetic Resonance in Imperfect Crystals

N. Bloembergen

Technical Report No. 199

A systematic survey is made how various kinds of imperfections in a crystalline lattice will affect the position, breadth, shape and relaxation time of the nuclear magnetic resonance. In accordance with Seitz's classification the following imperfections are considered: (a) dislocations; (b) vacant lattice sites and interstitial atoms; (c) foreign atoms in either interstitial or substitutional position; (d) electrons and holes; (e) phonons; (f) excitons. Their interaction with the magnetic dipole moment and the electric quadrupole moment of the nuclei at the normal lattice sites is discussed and the available experimental information is reviewed.

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